PROJECTION OBJECTIVE FOR A MICROLITHOGRAPHIC PROJECTION EXPOSURE APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to microlithographic projection exposure apparatuses as are used to manufacture large-scale integrated electrical circuits and other microstructured components. More particular, the invention relates to a projection objective of such an apparatus that is designed for immersion operation.

2. Description of Related Art

Integrated electrical circuits and other microstructured components are normally produced by applying a plurality of structured layers to a suitable substrate, which may be, for example, a silicon wafer. To structure the layers, they are first covered with a photoresist that is sensitive to light of a certain wavelength range. The wafer coated in this way is then exposed in a projection exposure apparatus. In this operation, a pattern of structures contained in a mask is imaged on the photoresist with the aid of a projection objective. Since the imaging scale is generally smaller than 1, such projec-

tion objectives are frequently also referred to as reduction objectives.

After the development of the photoresist, the wafer is subjected to an etching or deposition process, as a result of which the uppermost layer is structured in accordance with the pattern on the mask. The photoresist still remaining is then removed from the remaining parts of the layer. This process is repeated until all the layers have been applied to the wafer.

One of the most prominent objects in the design of projection exposure apparatuses is to be able to define lithographically structures having increasingly smaller dimensions on the wafer. Small structures result in high integration densities, which generally have a favorable effect on the performance of the microstructured components produced with the aid of such apparatuses.

One of the most important parameters that determine the minimum size of the structures to be lithographically defined is the resolution of the projection objective. Since the resolution of the projection objectives decreases as the wavelength of the projection light becomes smaller, one approach to achieve smaller resolutions is to use projection light with ever-shorter wavelengths. The shortest currently used wavelengths are in the deep ultraviolet (DUV) spectral range and are 193 nm and 157 nm.

Another approach to decrease the resolution is to introduce an immersion liquid having high refractive index into the gap that remains between a final lens element on the image side of the projection objective and the photoresist or another photosensitive layer to be exposed. Projection objectives that are designed for immersion operation and are therefore also referred to as immersion objective may reach numerical apertures of more than 1, for example 1.3 or 1.4. The term "immersion liquid" shall, in the context of this application, relate also to what is commonly referrd to as "solid immersion". In the case of solid immersion, the immersion liquid is in fact a solid medium that, however, does not get in direct contact with the photoresist but is spaced apart from it by a distance that is only a fraction of the wavelength used. This ensures that the laws of geometrical optics do not apply such that no total reflection occurs.

Immersion operation, however, does not only allow to achieve very high numerical apertures and, consequently, a smaller resolution, but it also has a favorable effect on the depth of focus. The higher the depth of focus is, the lower are the requirements imposed on an exact positioning of the wafer in the image plane of the projection objective. Apart from that, it has been found out that immersion operation considerably relaxes certain design constraints and simplifies the correction of aberrations if the numerical aperture is not increased.

In the meantime, immersion liquids have been developed whose refractive index is significantly above that of deionized water (n_{H2O} = 1.43) and that are nevertheless also highly transparent and resistant to projection light of the wavelength 193 nm. When using immersion liquids with such high refractive indices, it may happen that the refractive index of the immersion liquid is greater than the refractive index of the material of which the last optical element on the image side is composed. In conventional projection objectives having a last optical element with a plane surface on the image side, the maximum numerical aperture is restricted by the refractive index of this last optical element. If this optical element is, for example, made of quartz glass, an increase in the numerical aperture beyond the refractive index of quartz glass (n_{SiO2} = 1.56) is not possible although the refractive index of the immersion liquid is even higher.

Document JP 2000-058436 A discloses a projection exposure apparatus having a projection objective can be used both in dry and in immersion operation. When switching to immersion operation, an additional lens element having a concave surface on the image side is introduced into the gap between the last optical element of the projection objective and the wafer. The interspace between the additional lens element and the wafer may be filled with an immersion liquid, for example an oil. This document does not disclose the refractive indices of the immersion liquid and the additional lens element.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide an immersion projection objective in which the refractive index of the last optical element on the image side is larger is smaller than the refractive index of the immersion liquid, but having a numerical aperture that is not restricted by the refractive index of the last optical element.

This object is achieved in that, during immersion operation, the immersion liquid is convexly curved towards the object plane.

As a result of the convex curvature of the immersion liquid towards the object plane, the angles of incidence at which projection light rays impinge on the interface between an adjoining medium, e.g. the last optical element on the image side, and the immersion liquid are reduced. Thus a light ray that would be totally reflected by a flat interface can now contribute to the image, and this, in turn, allows higher numerical apertures that can also be above the refractive index of the last optical element on the image side. In this way the numerical aperture is limited only by the refractive index of the immersion liquid, but not by the refractive index of the medium that adjoins the immersion liquid on the object side.

The simplest way of achieving an immersion liquid that is convexly curved towards the object plane is to allow the immersion liquid to adjoin directly a concavely curved image-side surface of the last optical element of the projection objective. The curvature of the immersion liquid is then unalterably fixed by the curvature of this surface.

In order to prevent an undesired drainage of the immersion liquid from the cavity that is formed by the concavely curved image-side surface of the last optical element, this surface may be surrounded circumferentially by a drainage barrier. This may, for example, be a ring that is joined to the last optical element and/or a housing of the projection objective. The ring, which may be composed, for example, of a standard lens material such as quartz glass or calcium fluoride (CaF_2), but also of a ceramic or of hardened steel, is preferably provided on the inside with a coating that prevents contamination of the immersion liquid by the ring. Such a ring is also advantageous if the refractive index of the immersion liquid is equal to or smaller than the refractive index of the medium that adjoins the immersion liquid on the object side.

The image-side surface of the last optical element may be spherical. Calculations have shown that the radius of curvature may advantageously be selected to be between 0.9 times and 1.5 times and preferably 1.3 times the ax-

ial distance (i.e. vertex distance) between the this surface and the image plane. Such a configuration, which is also advantageous if the refractive index of the immersion liquid is equal to or smaller than the refractive index of the medium that adjoins the immersion liquid on the object side, has the advantage the high angles of incidence at the object side interface of the immersion liquid are avoided. Such high angles usually result in a strong sensitivity of the interface to design and manufacturing deficiencies. From this point of view, the angles of incidence should be as small as possible. This generally requires a very large curvature (i.e. a small radius of curvature) of the object-side interface of the immersion liquid.

Another way of obtaining an interface of the immersion liquid that is convexly curved toward the object plane is to introduce an intermediate liquid between the last optical element and the immersion liquid. This intermediate liquid is not miscible with the immersion liquid and forms a curved interface in an electric field during immersion operation. Such a configuration is also advantageous if the refractive index of the immersion liquid is equal to or smaller than the refractive index of the medium that adjoins the immersion liquid on the object side.

This approach makes use of an effect that is also known as "electrowetting". If the magnitude of the electric

field is altered, this is accompanied by an alteration in the curvature of the interface. This effect has hitherto been used, however, only for autofocus lenses for CCD or CMOS sensors on components that are produced by *Varioptic*, France.

The more the electrical conductivities of the two liquids differ from one another, the greater is the curvature of the interface. A large difference may be achieved if one of the two liquids, for example the intermediate liquid, is electrically conductive and the other liquid, for example the immersion liquid, is electrically insulating.

It is furthermore advantageous if the intermediate liquid has substantially the same density as the immersion liquid since no buoyancy forces can occur and, consequently, the shape of the interface is independent of the position of the arrangement in space.

The refractive index of the intermediate liquid should be less than the refractive index of the immersion liquid, but it may be less or greater than the refractive index of the last optical element on the image side.

Preferably, the electric field that is necessary to form the curved interface is generated by an electrode. A symmetrical formation of the interface can be achieved, for example, by using an annular cone electrode that is disposed between the last optical element and the image

plane. The curvature of the interface can be continuously varied in this way by varying a voltage applied to the electrode. This can be exploited in order to correct certain imaging properties of the projection objective.

Above it has been mentioned that it may be desirable to have a strongly curved interface between the immersion liquid and the medium adjoining to the object side, because this simplifies the correction of imaging aberrations. However, it has also significant advantages if the curvature of this interface is small. This is because a large curvature generally leads to the formation of a cavity within the last optical element. Such a cavity has several drawbacks. For example, it favors the occurrence of undesired turbulences within the cavity if a flow of the immersion liquid has to maintained, for example for reasons of temperature stability and for purifying the liquid. Furthermore, highly refractive immersion liquids have a somewhat higher absorption than lens materials. For that reasons the maximum geometrical path lengths within the immersion liquid should be kept small. Finally, a small curvature simplifies the access to the image side surface of the last optical element for cleaning purposes.

Therefore it is generally preferred if the immersion liquid forms a convexly curved interface with a medium adjoining the immersion liquid towards the object plane such that light rays pass the interface with a maximum

angle of incidence whose sine is between 0.98 and 0.5, more preferably between 0.95 and 0.85, and even more preferably between 0.94 and 0.87. The latter values correspond to angles of incidence of 60° and 70°, respectively. The angle of incidence here denotes the angle between the light ray and a surface normal at the point where the light ray impinges on the surface. These configurations are also advantageous if the refractive index of the immersion liquid is equal to or smaller than the refractive index of the medium that adjoins the immersion liquid on the object side.

The very high numerical apertures possible according to the invention, which may be, for example, 1.6 and above, require, under some circumstances, a novel design of the projection objective. In this connection, a catadioptric projection objective comprising at least two imaging mirrors in which at least two intermediate images may be advantageous. Such a configuration is also advantageous if the refractive index of the immersion liquid is equal to or smaller than the refractive index of the medium that adjoins the immersion liquid on the object side.

BRIEF DESCRIPTION OF THE DRAWINGS

Various features and advantages of the present invention may be more readily understood with reference to the following detailed description taken in conjunction with the accompanying drawing in which:

Figure 1 shows a meridian section through a microlithographic projection exposure apparatus having a projection objective according to the invention in a considerably simplified view that is not to scale;

Figure 2 shows an enlarged view of the image-side end of the projection objective shown in Figure 1;

Figure 3 shows an enlarged view similar to Figure 2 for an alternative embodiment with a drainage barrier;

Figure 4 shows the image-side end of a projection objective in accordance with another exemplary embodiment in which an intermediate liquid has been introduced between the immersion liquid and the last optical element on the image side;

Figure 5 shows details of the geometrical conditions at the image-side end of a projection objective according to the invention;

Figure 6 shows a meridian section through a catadioptric projection objective in accordance with an embodiment the present invention;

Figure 7 shows a meridian section through a catadioptric projection objective in accordance with a further embodiment the present invention;

Figure 8 shows a meridian section through a catadioptric projection objective in accordance with another embodiment the present invention;

Figure 9 shows a meridian section through a complete catadioptric projection objective in accordance with still another embodiment the present invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

Figure 1 shows a meridian section through a microlithographic projection exposure apparatus denoted in its entirety by 110 in a considerably simplified view that is not to scale. The projection exposure apparatus 110 comprises an illuminating system 112 for generating projection light 113 including a light source 114, illumination optics indicated by 116 and a diaphragm 118. In the exemplary embodiment shown, the projection light 113 has a wavelength of 193 nm.

The projection exposure apparatus 110 furthermore includes a projection objective 120 that comprises a multiplicity of lens elements, of which, for the sake of clarity, only a few are indicated by way of example in Figure 1 and are denoted by L1 to L5. The projection objective 120 images a mask 124 disposed in an object plane 122 of the projection objective 120 on a reduced scale on a photosensitive layer 126. The layer 126, which may be composed of a photoresist, is disposed in an image plane 128 of the projection objective 120 and is applied to a substrate 130. The photosensitive layer 126 may itself be composed of a plurality of layers and may also comprise antireflection layers, as is known in the art as such.

An immersion liquid 134 has been introduced into a gap 132 that remains between the last lens element L5 on the image side and the photosensitive layer 126.

This can be seen more clearly in Figure 2 that shows the image-side end of the projection objective 120 on an enlarged scale. The last lens element L5 on the image side has, on the image side, a surface 136 that is concavely curved. The gap 132 between the last lens element L5 on the image side and the photosensitive layer 126, which is usually flat at both ends, now transforms into a kind of cavity.

The surface 136 is approximately of spherical shell shape, the radius of curvature being denoted in Figure 2

by R. In this arrangement, the radius of curvature R is about 1.3 times the axial distance s between the last lens element L5 on the image side and the photosensitive layer 126.

The immersion liquid 134 has a refractive index n_L that is greater than the refractive index of the material n_1 of which the last lens element L5 on the image side is composed. If, for example, quartz glass or calcium fluoride is used as material, a liquid should be chosen whose refractive index n_L is above 1.56 or 1.5. This can be achieved, for example, by adding sulphates, alkalis such as caesium, or phosphates to water, as is described on Internet page www.eetimes.com/semi/news/OEG20040128S0017. These immersion liquids have sufficient transparency and stability even at wavelengths in the deep ultraviolet spectral range. If the projection exposure apparatus 110 is designed for longer wavelengths, for example for wavelengths in the visible spectral range, conventional immersion liquids having high refractive index, such as, for example, cedarwood oil, carbon disulphide or monobromonaphthalene may also be used as immersion liquid.

Since the immersion liquid forms, with respect to the object plane 122, a convexly curved interface 139 with the last lens element L5 on the image side, only relatively small beam incidence angles occur at said interface 139. This is shown in Figure 2 by way of example for aperture rays 113a and 113b having a maximum aperture angles α. As

a result, reflection losses at said interface are correspondingly small. Thus rays having large aperture angles with respect to an optical axis OA of the projection objective 120 may also contribute to forming an image of the mask 124, with the result that it is possible to achieve with the projection objective 120 numerical apertures that extend up to the refractive index n_L of the immersion liquid 134. If, on the other hand, the interface 139 were plane, as is usual in the prior art, said rays would be totally reflected at the interface between the last lens element L5 and the immersion liquid.

Figure 3 shows a projection objective 120 in accordance with another exemplary embodiment in a view along the lines of Figure 2. Identical parts are characterized in the figure by identical reference numerals.

The projection objective 120' differs from the projection objective 120 shown in Figures 1 and 2 only in that a ring 140 is tightly joined to the last lens element L5 and a housing 141 of the projection objective 120. The ring 140 functions as a drainage barrier for the immersion liquid 134. Such a drainage barrier may be particularly advantageous if the surface 136 of the last lens element L5 on the image side is strongly curved since then the gap 132 has a large maximum extension along the optical axis OA. Accordingly, the hydrostatic pressure of the immersion liquid 134 is relatively high. Without a drainage barrier, said pressure may ultimately have the

result that the immersion liquid 134 is forced out of the cavity into the surrounding gap 132 between the projection objective 120 and the photosensitive layer 126 so that a surrounding gas may enter the cavity.

The ring 140 may be composed, for example, of a standard lens material such as quartz glass or calcium chloride, but also of other materials, such as Invar™ nickel alloy, stainless steel or (glass) ceramic.

Figure 4 shows an image-side end of a projection objective 120" in accordance with a further exemplary embodiment in which a curvature of the immersion liquid 134 is achieved in another way.

In the projection objective 120", the immersion liquid 134 does not directly adjoin a last lens element L5" on the image side. Instead, a further liquid, which is referred to in the following as intermediate liquid 142, is situated between the last lens element L5" on the image side and the immersion liquid 134. The intermediate liquid 142 is, in the embodiment shown, water to which ions have been added. Due to the ions the water becomes electrically conductive. The immersion liquid 134, which also in this case has a greater refractive index than the last lens element L5", is electrically insulating. For wavelengths of the projection light that are in the visible spectral range, the oils and naphthalenes already men-

tioned above are, for example, suitable as immersion liquid 134.

The intermediate liquid 142 completely fills the space that remains between an image-side surface 136" of the last lens element L5" on the image side and the immersion liquid 134. The surface 136" is convexly curved in the exemplary embodiment shown, but the latter may also be a plane surface. Adjacent to a ring 140" that, as in the exemplary embodiment described above, has the function of a drainage barrier, a likewise annular conical electrode 146 is provided that is connected to a controllable voltage source 147. Applied to the conical electrode 146 is an insulator layer 148 that, together with the photosensitive layer 126, ensures continuous insulation of the immersion liquid 134 with respect to the image plane. The voltage source 147 generates an alternating voltage whose frequency is between 100 kHz and 500 kHz. The voltage applied to the conical electrode 146 is in the order of magnitude of about 40 V.

When the alternating voltage is applied to the conical electrode 146, the electrowetting effect known as such has the result that the interface 139 between the immersion liquid 134 and the intermediate liquid 142 convexly curves towards the object plane 122. The cause of this curvature is capillary forces that, together with the unalterability of the total volume and the tendency to the formation of a minimum surface, generate, to a good

approximation, a spherical interface 139 if a sufficiently high alternating voltage is applied to electrode 146.

If the alternating voltage is now reduced, the curvature of the interface 139 decreases. In Figure 4 this is indicated by an interface 139' shown as a broken line. The refractive index of the liquid lens formed by the immersion liquid 134 can consequently be continuously varied in a simple way, namely by altering the electrical alternating voltage applied to the conical electrode 146. For the sake of completeness, it may also be mentioned at this point that the curvature of the interface 139 does not necessarily require an alternating voltage, but may also be achieved with a direct voltage.

Also in this embodiment, the interface of the immersion liquid 134 that is convexly curved towards the object plane 122 has the effect that a numerical aperture can be achieved that is limited not by the refractive index of the last lens element L5" but only by the refractive index of the immersion liquid 134.

The continuous variability of the refractive power of the liquid lens formed by the immersion liquid 134 can advantageously also be used at other locations in the projection objective. Advantageously, such a liquid lens can be used at positions inside the projection objective that are exposed to particularly high light intensities. Degradation phenomena, such as occur in the case of conven-

tional solid lenses, can be suppressed in this way or at least be repaired by simply replacing the immersion liquid. Incidentally, corresponding remarks also apply to the embodiments shown in Figures 2 and 3.

Figure 5 shows an image-side end of a projection objective according to a still further exemplary embodiment. Here the last lens element L205 has a spherical surface 236 facing towards the image plane that has a smaller concave curvature, i.e. a larger radius R, than the lens element L5 in the embodiments shown in Figures 2 and 3. In the following the geometrical conditions at the interface between the last lens element L205 and the immersion liquid 134 will be discussed in further detail.

Reference numeral AR denotes an aperture ray having a maximum aperture angle φ. The aperture ray AR impinges on the photosensitive layer 126 at a peripheral point of the image field at a height h with respect to the optical axis OA. The aperture ray AR has an angle of incidence α and an angle of refraction β at the interface between the last lens element L205 and the immersion liquid 134. The distance between the vertex of the last surface 236 of the lens element L205 and the image plane in which the photosensitive layer 126 is positioned is denoted by s.

Projection objectives are basically characterized by two quantities, namely the image-side numerical aperture

$$NA = n \cdot \sin(\varphi)$$

and the quantity 2h, i.e. the diameter of a circle around the optical axis OA on which an image can be formed.

From the image-side numerical aperture NA certain geometrical properties can be derived which ensure that the light can propagate through the last lens element and immersion liquid without being reflected at the interfaces. However, the design requirements applied to the last lens element are, in practice, somewhat stricter than those that can be derived solely from the image-side numerical aperture. For example, the angle of incidence α should not exceed a certain value that is, for example, about 75°, and more preferably 70°. This is because experience shows that projection objectives having larger angles of incidence α require very complex measures to achieve a good aberration correction and a reduced sensitivity to manufacturing tolerances and changing environmental conditions.

At present projection objectives for dry operation achieve an image-side NA close to about 0.95. This means that the numerical aperture NA does not exceed 95% of the refractive index of the medium (usually a gas or a mixture of gases such as air) that immediately precedes the image plane. In such dry projection objectives the maximum angles of incidence are in the order of about 70°, in

particular at the last surfaces close to the image plane but also at other surfaces of lens elements.

Since these considerations also apply to immersion objectives, the angles of incidence should be kept below these values. From geometrical considerations it becomes clear that the stronger the curvature of the surface 236 is, the smaller are the angles of incidence. Thus a strong curvature ensures that the angles of incidence do not go beyond these values.

The surface 236 of the lens element L205 should, on the other hand, not be too severely curved. This is due to the fact that a too severely curvature may result in increased problems with respect to flow mechanics, contamination and temperature sensitivity of the immersion liquid 134. For example, it may be difficult to achieve a homogenous and constant temperature of the immersion liquid 134, and the immersion liquid 134 may be enclosed in such a way within a strongly convex cavity that replacing the immersion liquid, for example for purging reasons, becomes a very complex task.

It has been found out that a good compromise is achieved if the following condition holds for the maximum angle of incidence α:

$$0.95 > \sin(\alpha) > 0.85.$$

In the following a formula is derived that specifies a suitable curvature ρ as a function of NA = n.sin(φ), distance s, image height h and the refractive indices n′, n of the last lens element L205 and the immersion liquid 134, respectively, so that the sine of the angle of incidence α does not exceed a certain advantageous and practicable value. Such a value was found to be sin(α) < κ, where κ = 0.95. Using the law of refraction, it follows that

$$\left|\frac{n}{n'}\sin(\beta)\right| > \kappa$$

According to simple geometrical considerations, it can be deduced therefrom that

$$\left|\frac{n}{n'}(s\rho - 1)\sin(\varphi)\right| > \kappa$$

Thus

$$\rho > \frac{\left(1 - \frac{n' \cdot \kappa}{NA}\right)}{s}$$

is the condition for minimum surface curvature. For the radius R = 1/ρ this gives

$$R > \frac{s}{\left(1 - \frac{n' \cdot \kappa}{NA}\right)} \quad .$$

For an exemplary numerical aperture NA = 1.5 and SiO_2 as material for the last lens element L205 with n' = 1.56, this results in

$$R > m \cdot s$$

with m ≈ 83. For s = 2 mm, this leads to a radius R of about 167 mm for the maximum radius of curvature.

If, in addition, the aperture rays of the outermost image point are taken into account in the case of a finite image field, it is sufficient for this purpose to substitute the distance s by s′ according to

$$s' = s \frac{h}{\tan \varphi}$$

in the above formulae. For a maximum field height h, it then follows for the minimum curvature ρ

$$\rho > \left(1 - \frac{n' \cdot \kappa}{NA}\right) \Big/ \left(s - \frac{h}{\tan \varphi}\right)$$

If one starts with a projection objective having the above mentioned parameters, i.e. NA = 1.5 and n' = 1.56,

and if one further assumes that the maximum field height h is 15 mm, the maximum radius of curvature R should be below m = 83 times (s - 5.57 mm). For s = 8 mm, this results in a maximum radius of curvature R of approximately 200 mm, and for s = 10 mm R is approximately 375 mm.

If, for example, κ is selected to be 0.95 and an immersion liquid with a refractive index of n = 1.43 is used, a numerical aperture NA = 1.35 may be realized with a last lens element L205 that is made of SiO_2 and which has a distance s = 2 mm to the image plane and has a maximum radius of curvature below approximately 80 mm. The aforementioned detrimental effects that occur in the case of large curvatures can be minimized if the maximum radius of the surface is not only below the given values, but at least substantially identical to these values.

Apart from the fact that the maximum angle of incidence should not exceed certain upper and lower limits as is explained above, it should be ensured that the light rays rather quickly converge if one looks from a point on the image plane towards the object plane. Otherwise optical elements with very large diameters would be required. This qualitative design rule can be mathematically expressed in the following way: If k, l, m are the three direction cosines of an aperture ray and n is the refractive within a medium with $k^2 + l^2 + m^2 = n^2$, there should be no volume in the objective (particularly in the vicinity of the image plane) in which $(k^2 + l^2)/n^2 > K_0$. The

limit K_0 may be selected to be $K_0 = 0.95$ or even better $K_0 = 0.85$.

Figure 6 shows a meridian section through a first exemplary embodiment of the projection objective 120 shown in Figures 1 and 2. The design data of the projection objective are listed in Table 1; radii and thicknesses are specified in millimeters. The numerals above the projection objective point to selected surfaces of optical elements. Surfaces that are characterized by groups of short bars are aspherically curved. The curvature of said surfaces is described by the aspherical formula below:

$$z = \frac{ch^2}{1 + \sqrt{1 - (1 + k)\, c^2 h^2}} + Ah^4 + Bh^6 + Ch^8 + Dh^{10} + Eh^{12} + Fh^{14}$$

In this equation, z is the saggita of the respective surface parallel to the optical axis, h is the radial distance from the optical axis, $c = 1/R$ is the curvature at the vertex of the respective surface where R is the radius of curvature, k is the conical constant and A, B, C, D, E *and* F are the aspherical constants listed in Table 2. In the exemplary embodiment, the spherical constant k *equals zero.*

The projection objective 120 contains two aspherical mirrors S1 and S2 between which two (not optimally corrected) intermediate images are produced. The projection

objective 120 is designed for a wavelength of 193 nm and a refractive index n_L of the immersion liquid of 1.60. The linear magnification of the projection objective 120 is $\beta = -0.25$ and the numerical aperture is NA = 1.4. Some additional improvements, however, make it possible to achieve without difficulty also a numerical aperture NA that just reaches the refractive index of the immersion medium and is, consequently, only slightly less than 1.6.

Figures 7 to 9 show meridian sections through three further exemplary embodiments of the projection objective 120 shown in Figures 1 and 2. The design data and aspherical constants of the projection objective shown in Figure 7 are listed in Tables 3 and 4; Tables 5, 6 and Tables 7, 8 list the design data and aspherical constants for the embodiments shown in Figure 8 and 9, respectively.

The projection objectives shown in Figures 7 to 9 all have an image-side numerical aperture NA = 1.40 and an immersion liquid with a refractive index of $n_L = 1.60$. Thus this refractive index is always greater than the refractive index of the last lens element made of CaF_2, i.e. $n_L > n_{CaF2}$.

The projection objective shown in Figure 7, which is designed for a wavelength $\lambda = 193$ nm, is non-achromatized and has a last lens element LL7 with a strongly concavely curved image-side surface that forms a kind of cavity for

the immersion liquid 134. The wavefront is corrected to about 2/100 λ.

The projection objective shown in Figure 8 is designed for a wavelength λ = 157 nm and is achromatized. The image-side surface of the last lens element LL8 is even stronger concavely curved; apart from that, the radius of curvature is almost identical with the axial distance between the last lens element LL8 and the image plane, i.e. the center of curvature lies substantially within the image plane. As a result, the immersion liquid 134 has a large maximum thickness. Although the refractive index of CaF_2 is about n_{CaF2} = 1.56 at λ = 157 nm, the refractive index of the immersion liquid is still assumed to be larger (n_L = 1.60). The wavefront is corrected to about 4/100 λ.

The projection objective shown in Figure 9 is designed for a wavelength λ = 193 nm and is non-achromatized. The image-side surface of the last lens element LL9 has only a small concave curvature so that the immersion liquid 934 forms almost a flat layer. The radius of curvature is significantly (about a factor 10) greater than the axial distance between the last lens element LL9 and the image plane, i.e. there is a substantial distance between the center of curvature and the image plane. The maximum angel of incidence at the interface between the last lens element LL9 and the immersion liquid 934 is about 67°

(i.e. $\sin \alpha = 0.92$). The wavefront is corrected to about 5/100 λ.

When comparing the wavefront errors in the similar embodiments shown in Figures 7 and 9, it becomes clear that the design of Figure 7 with its greater curvature of the image-side surface of the last lens element LL7 allows to achieve a much better wavefront correction (2/100 λ vs. 5/100 λ). However, although the projection objective shown in Figure 9 is not as well corrected as the projection objective shown in Figure 7, due to the comparatively large radius of curvature there is only a small cavity underneath the last lens element LL9 which is advantageous for the reasons that have been mentioned above.

It goes without saying that the present invention is not restricted to the use in catadioptric projection objectives as have been described above. The invention can also advantageously be used in projection objectives having a smaller or larger number of intermediate images than in the embodiments shown, and also in dioptric projection objectives with or without any intermediate images. In addition, the optical axis may also extend through the center of the image field. Examples of further suitable lens designs are to be found, for example, in US 2002/0196533 A1, WO 01/050171 A1, WO 02/093209 A2 and US 6496306 A.

Table 1: Design data

SURFACE	RADIUS	ASPHERICAL	THICKNESS	MATERIAL
Object plane	∞		37,648	
1	210,931		21,995	SiO_2
2	909,02		1,605	
3	673,572		22,728	SiO_2
4	-338,735	x	33,19	
5	130,215	x	8,994	SiO_2
6	119,808		36,001	
7	216		40,356	SiO_2
8	-210,59		0,939	
9	97,24		49,504	SiO_2
10	216,208	x	8,164	
12	-65,704		49,734	SiO_2
Diaphragm	∞		49,302	
13	-113,325		55,26	
14	-6210,149	x	70,31	SiO_2
15	-195,536		0,962	
16	3980,16		65,997	SiO_2
17	-473,059		277,072	
18	-225,942	x	246,731	Mirror
19	193,745	x	294,329	Mirror
20	-338,56	x	17,389	SiO_2
21	-206,244		8,884	
22	-148,97		34,064	SiO_2
23	129,921	x	40,529	
24	-2704,885		33,192	SiO_2
25	-195,599		0,946	
26	-794,214	x	30,169	SiO_2
27	-479,39		24,236	
28	-311,778	x	100,056	SiO_2
29	-159,333		28,806	
30	309,839		43,609	SiO_2
31	836,077	x	0,951	
32	225,096		55,667	SiO_2
33	687,556		0,945	
34	154,575		64,278	SiO_2
35	911,8	x	0,932	
36	89,986		44,143	SiO_2
37	199,475	x	0,878	
38	61,984		9,635	SiO_2
39	35,475		34,43	Liquid
40	∞			Resist

Table 2: Aspherical constants

	Surface 4		Surface 5		Surface10
A	5,36225288E-08	A	2,53854010E-08	A	4,51137087E-07
B	-5,17992581E-12	B	-1,22713179E-11	B	2,46833840E-11
C	8,49599769E-16	C	1,21417341E-15	C	5,78496960E-15
D	-7,57832730E-20	D	-1,92474180E-19	D	-4,39101683E-18
E	3,59228710E-24	E	2,08240691E-23	E	-5,64853356E-22
F	-9,16722201E-29	F	-9,29539601E-28	F	4,95744749E-26

	Surface 14		Surface 18		Surface 19
A	-8,48905023E-09	A	1,04673033E-08	A	-4,11099367E-09
B	1,45061822E-13	B	1,34351117E-13	B	-9,91828838E-14
C	-6,34351367E-18	C	1,03389626E-18	C	-7,93614779E-19
D	2,84301572E-22	D	5,16847878E-23	D	-1,66363646E-22
E	-8,24902650E-27	E	-1,23928686E-27	E	5,56486530E-27
F	1,27798308E-31	F	3,09904827E-32	F	-1,79683490E-31

	Surface 20		Surface 23		Surface 26
A	1,14749646E-07	A	-2,87603531E-08	A	-4,35420789E-08
B	-8,19248307E-12	B	-9,68432739E-12	B	-6,70429494E-13
C	8,78420843E-16	C	6,88099059E-16	C	-4,05835225E-17
D	-1,39638210E-19	D	-8,70009838E-20	D	-1,10658303E-20
E	2,09064504E-23	E	9,59884320E-24	E	4,80978147E-25
F	-2,15981914E-27	F	-5,07639229E-28	F	-5,35014389E-29

	Surface 28		Surface 31		Surface 35
A	-2,70754285E-08	A	4,38707762E-09	A	1,73743303E-08
B	-1,36708653E-12	B	-3,69893805E-13	B	1,60994523E-12
C	-2,46085956E-17	C	-4,93747026E-18	C	-1,71036162E-16
D	2,26651081E-21	D	4,05461849E-22	D	1,26964535E-20
E	-1,20009586E-25	E	-7,59674606E-27	E	-5,77497378E-25
F	9,28622501E-30	F	5,58403314E-32	F	1,55390733E-29
				G	-1,78430224E-34

	Surface 37
A	1,04975421E-07
B	1,94141448E-11
C	-2,31145732E-15
D	4,57201996E-19
E	-3,92356845E-23
F	2,35233647E-27

Table 3: Design data

SURFACE	RADIUS	THICKNESS	MATERIAL	INDEX	SEMIDIAM
0	∞	32.0000			65.50
1	∞	0.0000			80.45
2	332.4480	18.9959	SiO_2	1.560318	84.22
3	27083.8930	17.5539			85.42
4	-253.5666	26.7129	SiO_2	1.560318	86.06
5	-179.3607	164.1318			90.72
6	1920.0084	34.5089	SiO_2	1.560318	111.13
7	-279.4103	0.9461			111.59
8	213.6767	34.3917	SiO_2	1.560318	103.48
9	17137.3629	26.7484			100.67
10	-208.9766	9.4997	SiO_2	1.560318	99.22
11	-609.1513	0.9500			97.67
12	734.0560	18.8742	SiO_2	1.560318	95.00
13	-1380.9253	24.2008			93.32
14	∞	231.0887			81.98
15	252.7510	74.6720	SiO_2	1.560318	126.43
16	1098.5274	0.9492			121.38
17	268.9906	50.1845	SiO_2	1.560318	119.28
18	-463.5300	1.0915			117.08
19	697.8278	30.0054	SiO_2	1.560318	106.59
20	292.0140	120.0163			94.90
21	∞	9.9914			82.23
22	∞	-100.0083	Mirror	1.560318	142.10
23	-178.0803	-45.0048	SiO_2	1.560318	115.52
24	-663.9291	-95.3149			113.38
25	-237.9404	-15.0000	SiO_2	1.560318	115.72
26	-166.3412	-152.4364			111.11
27	222.8026	-15.0000	SiO_2	1.560318	127.22
28	539.8416	-94.3687			138.91
29	364.8709	94.3687	Mirror		167.04
30	539.8416	15.0000	SiO_2	1.560318	138.91
31	222.8026	152.4364			127.22
32	-166.3412	15.0000	SiO_2	1.560318	111.11
33	-237.9404	95.3149			115.72
34	-663.9291	45.0048	SiO_2	1.560318	113.38
35	-178.0803	100.0083			115.52
36	∞	94.5942			122.31
37	∞	-23.8903			91.10
38	∞	20.0000			179.89
39	254.8239	29.5175	SiO_2	1.560318	96.82
40	-2985.0549	36.7407			96.62
41	200.4128	45.9683	SiO_2	1.560318	106.20
42	-666.1976	170.5500			105.01

43	-95.1516	15.0000	SiO_2	1.560318	77.96
44	-643.9252	55.6492			95.09
45	-175.8508	-55.6492	Mirror		109.51
46	-643.9252	-15.0000	SiO_2	1.560318	95.09
47	-95.1516	-170.5500			77.96
48	-666.1976	-45.9683	SiO_2	1.560318	105.01
49	200.4128	-12.1735			106.20
50	∞	-24.5646			90.83
51	-2985.0549	-29.5175	SiO_2	1.560318	96.62
52	254.8239	-20.0000			96.82
53	∞	180.1673	Mirror		134.73
54	-148.5117	25.7491	SiO_2	1.560318	95.86
55	327.9861	43.1843			116.84
56	-496.1113	30.0070	SiO_2	1.560318	124.28
57	-252.6773	19.1777			130.89
58	1365.3904	68.1411	SiO_2	1.560318	165.17
59	-284.3746	73.5313			172.58
60	754.4880	93.5313	SiO_2	1.560318	234.19
61	-588.1067	54.2510			235.10
62	357.9132	85.3268	SiO_2	1.560318	221.99
63	-762.8649	0.9929			220.72
64	304.8598	57.6484	SiO_2	1.560318	181.91
65	1098.9629	0.9340			177.48
66	143.0811	62.6047	SiO_2	1.560318	127.33
67	347.6273	0.9010			177.47
68	79.6669	50.1800	CaF_2	1.501403	73.25
69	36.1540	21.2194	Liquid	1.600000	31.82
70	∞				19.38

Table 4: Aspherical constants

SURFACE	3	19	24	28	30
K	0	0	0	0	0
A	4.047232E-09	-4.175853E-08	-3.889430E-08	6.661869E-09	6.661869E-09
B	8.449241E-13	-5.621416E-13	2.260825E-13	2.899240E-13	2.899240E-13
C	5.603175E-17	-2.909466E-19	9.880822E-18	-1.932302E-17	-1.932302E-17
D	-4.004583E-21	3.690043E-22	-2.672567E-22	1.602360E-21	1.602360E-21
E	-8.168767E-25	2.119217E-26	4.717688E-26	-6.342246E-26	-6.342246E-26
F	2.123279E-29	-9.535588E-31	-3.817055E-30	1.183564E-30	1.183564E-30

SURFACE	34	39	44	46	52
K	0	0	0	0	0
A	-3.889430E-08	-2.037803E-08	-1.157857E-08	-1.157857E-08	-2.037803E-08
B	2.260825E-13	-6.612137E-13	1.455623E-12	1.455623E-12	-6.612137E-13
C	9.880822E-18	2.840028E-17	-5.746524E-17	-5.746524E-17	2.840028E-17
D	-2.672567E-22	-4.931922E-21	1.261354E-21	1.261354E-21	-4.931922E-21
E	4.717688E-26	4.142905E-25	4.054615E-25	4.054615E-25	4.142905E-25
F	-3.817055E-30	-1.562251E-29	-2.761361E-29	-2.761361E-29	-1.562251E-29

SURFACE	58	62	65	67
K	0	0	0	0
A	-1.679180E-08	-1.483428E-08	-9.489171E-09	-1.782977E-08
B	-5.846864E-14	-2.269457E-14	5.001612E-13	9.574096E-13
C	7.385649E-18	4.944523E-18	-1.283531E-17	7.878477E-17
D	-5.142028E-22	-1.410026E-22	-8.674473E-23	-7.167182E-21
E	1.479187E-26	1.643655E-27	7.103644E-27	2.682224E-25
F	-2.189903E-31	-7.668842E-33	-7.251904E-32	-3.423260E-30

Table 5: Design data

SURFACE	RADIUS	THICKNESS	MATERIAL	INDEX	SEMIDIAM
0	∞	32.0000			65.50
1	∞	0.0000			80.46
2	3568.5495	29.3610	CAF_2	1.555560	80.77
3	-306.4778	50.8080			84.99
4	-495.7015	32.5298	CAF_2	1.555560	97.37
5	-161.1181	81.4155			99.50
6	188.0753	36.2525	CAF_2	1.555560	93.00
7	-1013.7352	6.1886			90.93
8	288.3482	26.9703	CAF_2	1.555560	82.17
9	872.7887	32.5801			74.60
10	∞	47.8395			57.76
11	-76.3176	12.9591	CAF_2	1.555560	65.40
12	-82.8195	72.8834			71.21
13	494.0581	30.0025	CAF_2	1.555560	105.98
14	500.2689	0.9499			109.01
15	210.1705	55.9335	CAF_2	1.555560	115.54
16	-462.2471	0.9442			114.96
17	191.5029	28.1484	CAF_2	1.555560	104.19
18	469.5739	3.8083			100.65
19	313.4359	9.4935	CAF_2	1.555560	99.24
20	161.6230	115.1964			91.07
21	∞	14.7967			90.40
22	∞	-100.0183	Mirror		206.37
23	-247.2670	-56.5211	CAF_2	1.555560	148.25
24	1546.1350	-403.3917			147.84
25	500.0000	-25.0000	CAF_2	1.555560	142.88
26	-2059.5717	-87.3199			147.68
27	173.4701	-25.0000	CAF_2	1.555560	148.30
28	823.5657	-65.7941			193.66
29	295.8639	65.7941	Mirror		204.70
30	823.5657	25.0000	CAF_2	1.555560	193.66
31	173.4701	87.3199			148.30
32	-2059.5717	25.0000	CAF_2	1.555560	147.68
33	500.0000	403.3917			142.88
34	1546.1350	56.5211	CAF_2	1.555560	147.84
35	-247.2670	100.0183			148.25
36	∞	49.8789			125.86
37	∞	20.8278			89.12
38	∞	20.0000			149.02
39	215.5222	38.8898	CAF_2	1.555560	91.59
40	-548.9606	360.6137			90.02
41	-126.6780	15.0000	CAF_2	1.555560	120.92
42	-567.9480	48.8335			169.01
43	-224.2817	-48.8335	Mirror		171.87

44	-567.9480	-15.0000	CAF_2	1.555560	169.01
45	-126.6780	-314.8668			120.92
46	∞	-45.7487			81.94
47	-548.9606	-38.8898	CAF_2	1.555560	90.02
48	215.5222	-20.0000			91.59
49	∞	195.8787	Mirror		133.74
50	-121.2718	15.1499	CAF_2	1.555560	97.18
51	529.2614	24.3014			127.08
52	-8438.5548	64.5537	CAF_2	1.555560	137.42
53	-202.6253	25.2464			142.97
54	-1447.9251	63.0634	CAF_2	1.555560	168.91
55	-254.3816	80.5189			174.93
56	783.5550	57.0370	CAF_2	1.555560	203.06
57	-939.7625	70.4486			203.12
58	358.1334	55.4484	CAF_2	1.555560	186.96
59	5861.2627	0.9614			184.33
60	259.9889	36.5173	CAF_2	1.555560	161.62
61	371.5128	0.8975			156.47
62	134.7936	77.4909	CAF_2	1.555560	127.53
63	767.8631	0.7967			119.07
64	72.9080	48.3195	CAF_2	1.555560	70.97
65	29.7284	27.0563	IMMO16	1.600000	31.25
66	∞				19.39

Table 6: Aspherical constants

SURFACE	3	9	19	24	26
K	0	0	0	0	0
A	2.172737E-08	8.983641E-08	-5.825972E-08	-1.605889E-08	-2.779244E-10
B	1.718631E-12	-5.996759E-12	-6.306762E-13	4.504977E-16	-3.062909E-14
C	1.514127E-16	6.363808E-16	-2.783920E-17	3.596627E-21	1.861506E-18
D	-2.716770E-22	-3.998733E-20	-1.594705E-21	2.792862E-22	-2.425072E-22
E	-1.008203E-24	-5.130142E-24	2.956685E-25	-1.885291E-26	1.114443E-26
F	-1.157181E-28	1.266998E-28	-1.064251E-29	3.351694E-31	-2.553147E-31

SURFACE	28	30	32	34	39
K	0	0	0	0	0
A	4.632690E-09	4.632690E-09	-2.779244E-10	-1.605889E-08	-1.815667E-08
B	-3.213384E-14	-3.213384E-14	-3.062909E-14	4.504977E-16	-2.488991E-13
C	7.229632E-20	7.229632E-20	1.861506E-18	3.596627E-21	2.824306E-17
D	2.100335E-23	2.100335E-23	-2.425072E-22	2.792862E-22	-4.697303E-21
E	-5.592560E-28	-5.592560E-28	1.114443E-26	-1.885291E-26	3.415362E-25
F	6.249291E-33	6.249291E-33	-2.553147E-31	3.351694E-31	-9.509214E-30

SURFACE	42	44	48	54	59
K	0	0	0	0	0
A	-9.514646E-09	-9.514646E-09	-1.815667E-08	-1.031964E-08	8.72E-09
B	1.336864E-13	1.336864E-13	-2.488991E-13	-1.081794E-13	-2.71E-13
C	-4.722253E-18	-4.722253E-18	2.824306E-17	6.909628E-18	1.07E-17
D	1.120165E-22	1.120165E-22	-4.697303E-21	-3.648077E-22	-6.07E-22
E	-1.895395E-27	-1.895395E-27	3.415362E-25	9.693996E-27	1.40E-26
F	1.489410E-32	1.489410E-32	-9.509214E-30	-1.380442E-31	-1.10E-31

SURFACE	61	63
K	0	0
A	-2.45E-08	4.37E-08
B	6.62E-13	-8.96E-13
C	-1.32E-17	4.21E-17
D	6.68E-22	-3.88E-21
E	-1.47E-26	2.01E-25
F	1.14E-31	-3.84E-30

Table 7: Design data

SURFACE	RADIUS	THICKNESS	MATERIAL	INDEX	SEMIDIAM.
0	∞	32.0000			65.50
1	∞	0.0000			80.45
2	361.5503	30.0063	SiO_2	1.560318	83.87
3	3766.1854	29.9775			86.87
4	-313.0243	17.3177	SiO_2	1.560318	90.72
5	-211.2930	182.7697			93.19
6	-709.0001	29.1631	SiO_2	1.560318	120.83
7	-255.7121	13.1321			122.28
8	261.1325	45.4463	SiO_2	1.560318	118.65
9	-728.3260	29.9790			116.70
10	-209.1405	18.3161	SiO_2	1.560318	113.35
11	-2675.8307	4.7872			113.10
12	421.7508	25.2987	SiO_2	1.560318	112.42
13	-5576.5014	21.4392			111.29
14	∞	355.5491			103.93
15	249.8044	71.3667	SiO_2	1.560318	163.42
16	-4441.8089	32.5158			161.31
17	247.2422	37.4261	SiO_2	1.560318	135.08
18	797.4045	43.7199			130.81
19	665.9047	30.0078	SiO_2	1.560318	108.60
20	318.3673	120.0233			96.83
21	∞	9.9881			79.40
22	∞	-100.0079	Mirror		122.85
23	-145.3105	-45.0039	SiO_2	1.560318	107.21
24	-705.3999	-7.6524			104.90
25	-149.2286	-15.0000	SiO_2	1.560318	100.69
26	-107.5358	-125.6003			91.50
27	398.2665	-15.0000	SiO_2	1.560318	101.84
28	419.3212	-44.0802			104.16
29	398.6744	44.0802	Mirror		107.66
30	419.3212	15.0000	SiO_2	1.560318	104.16
31	398.2665	125.6003			101.84
32	-107.5358	15.0000	SiO_2	1.560318	91.50
33	-149.2286	7.6524			100.69
34	-705.3999	45.0039	SiO_2	1.560318	104.90
35	-145.3105	100.0079			107.21
36	∞	103.9571			130.84
37	∞	-33.2893			99.43
38	∞	20.0000			210.81
39	250.9147	31.5356	SiO_2	1.560318	101.23
40	-1057.0829	21.3930			102.52
41	202.0288	47.3927	SiO_2	1.560318	111.71
42	-941.7186	197.8094			110.48

43	-88.9067	15.0000	SiO_2	1.560318	72.67
44	-573.5619	23.1569			88.88
45	-142.4338	-23.1569	Mirror		89.38
46	-573.5619	-15.0000	SiO_2	1.560318	88.88
47	-88.9067	-197.8094			72.67
48	-941.7186	-47.3927	SiO_2	1.560318	110.48
49	202.0288	-11.3868			111.71
50	∞	-9.9896			92.32
51	-1057.0829	-31.5356	SiO_2	1.560318	102.52
52	250.9147	-20.0000			101.23
53	∞	209.4519	Mirror		135.07
54	-133.90811	9.4987	SiO_2	1.560318	97.71
55	406.9979	48.9711			119.82
56	-523.9173	41.1332	SiO_2	1.560318	135.89
57	-224.0541	29.8664			142.55
58	1367.6570	94.8234	SiO_2	1.560318	191.42
59	-271.7647	8.1788			198.87
60	667.9279	83.6854	SiO_2	1.560318	232.81
61	-808.5395	140.7841			233.01
62	286.6775	82.6895	SiO_2	1.560318	201.18
63	-1096.4782	0.9668			198.76
64	350.5350	35.6242	SiO_2	1.560318	164.87
65	884.2685	0.9173			159.58
66	115.9293	64.9068	SiO_2	1.560318	108.97
67	412.6826	0.8041			99.04
68	57.1792	41.0408	CaF_2	1.501403	55.06
69	99.9106	10.1713	Liquid	1.600000	30.68
70	∞				19.40

Table 8: Aspherical constants

SURFACE	3	19	24	28	30
K	0	0	0	0	0
A	-1.001534E-09	-4.128786E-08	-4.510495E-08	1.339665E-08	1.339665E-08
B	6.144615E-13	-4.980750E-13	6.742821E-13	1.482582E-12	1.482582E-12
C	1.247768E-16	2.649167E-18	3.004246E-17	-1.857530E-16	-1.857530E-16
D	-1.048854E-20	5.315992E-22	2.453737E-21	3.433994E-20	3.433994E-20
E	-4.463818E-25	-6.165935E-27	-3.687563E-25	-2.905941E-24	-2.905941E-24
F	6.154983E-30	1.945950E-32	-1.491146E-30	1.237374E-28	1.237374E-28

SURFACE	34	39	44	46	52
K	0	0	0	0	0
A	-4.510495E-08	-2.582589E-08	-1.589920E-08	-1.589920E-08	-2.582589E-08
B	6.742821E-13	-4.336537E-13	1.112204E-12	1.112204E-12	-4.336537E-13
C	3.004246E-17	5.153775E-17	-2.537422E-17	-2.537422E-17	5.153775E-17
D	2.453737E-21	-7.829187E-21	-5.148293E-21	-5.148293E-21	-7.829187E-21
E	-3.687563E-25	5.696031E-25	8.322199E-25	8.322199E-25	5.696031E-25
F	-1.491146E-30	-1.711252E-29	-2.485886E-29	-2.485886E-29	-1.711252E-29

SURFACE	58	62	65	67
K	0	0	0	0
A	-1.313863E-08	-1.809441E-08	-1.821041E-09	-4.599046E-10
B	1.817234E-14	-2.428724E-14	4.495016E-13	3.983791E-12
C	2.355838E-18	1.168088E-17	-7.637258E-18	-1.382332E-16
D	-1.447425E-22	-4.545469E-22	-1.610477E-21	-2.858839E-21
E	3.333235E-22	7.354258E-27	7.379400E-26	4.614539E-25
F	-4.355238E-32	-4.766510E-32	-9.483899E-31	-1.411510E-29